# TOP QUARK PAIR PRODUCTION CROSS SECTION AT THE TEVATRON
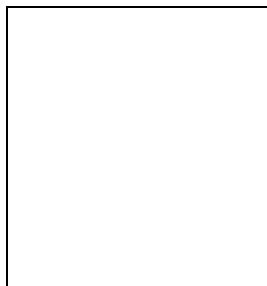
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Top quark pair production cross section has been measured at the Tevatron by CDF and DØ collaborations using different channels and methods, in order to test standard model predictions, and to search for new physics hints affecting the $t\bar{t}$ production mechanism or decay. Measurements are carried out with an integrated luminosity of 1.0 to 2.0 fb$^{-1}$, and are found to be consistent with standard model expectations.

## 1 Introduction

At the Tevatron $p\bar{p}$ collider top quarks are produced mainly in pairs through quark-antiquark annihilation ($\sim 85\%$) and gluon-gluon fusion ($\sim 15\%$) processes. In the standard model (SM) the calculated cross section for pair production is $6.7^{+0.7}_{-0.9}$ pb [1] for a reference top mass of 175 GeV/$c^2$, and varies linearly with a slope of $-0.2$ pb/GeV/$c^2$ with the top quark mass in the range 170 GeV/$c^2 < m_t < 190$ GeV/$c^2$. Accurate measurements of the $t\bar{t}$ production cross section serve as important test of QCD calculation, and provide probes toward new physics signals involving non-SM production processes or $t\bar{t}$ decays. Because the CKM element $V_{tb}$ is close to unity and $m_t$ is large, the SM top quark decays to a $W$ boson and a $b$ quark almost 100% of the time. The final state of top quark pair production thus includes two $W$ bosons and two $b$-quark jets. The $t\bar{t}$ experimental signatures are in general classified into three main categories: the *di-lepton* category represents the case in which both $W$ bosons decay leptonically; the *lepton+jets* signature arises when one of the $W$ decays hadronically and the other into $l\nu_l$ (where $l = e, \mu, \tau$); finally, the *all-hadronic* channel corresponds to the case in which both $W$ bosons decay into quarks. In this proceeding a review of cross section measurements in various decays channels and using different methods will be given, followed by a short description of some related searches for new physics hints.

## 2  Top pair production cross section measurements

### 2.1  The dilepton channels

The $t\bar{t}$ dilepton channel accounts for 10.3% of the total SM branching ratio. The experimental signature for these decays consist of two high-$p_T$, opposite sign leptons ($p_T \geq 15$ GeV/$c$), missing transverse energy ($\not{E}_T \geq 20 \div 30$ GeV) and two or more high-$E_T$ jets from $b$-quark hadronization ($E_T \geq 15 \div 20$ GeV). The physics backgrounds to the $t\bar{t}$ signal are due mainly to $Z/\gamma^*$+jets and diboson production ($WW/WZ/ZZ$+jets), and are estimated from Monte Carlo simulation. Instrumental backgrounds are generated by lepton mis-identification (*i.e.* from badly reconstructed jets), artificial $\not{E}_T$ from detector resolution effects or mis-measured jets, and by mis-identified $b-$jets in analyses exploiting $b$-tagging techniques. These background are estimated directly from data.

DØ reports a combination of two analyses in the dilepton channel using 1.05 fb$^{-1}$. In the standard dilepton analysis two well-identified and isolated leptons are used to discriminate the $t\bar{t}$ signal from backgrounds. On the other hand, the so-called lepton+track analysis relaxes the identification requirements on the second lepton to an isolated track and restores the signal to background ratio by requiring $b$-jets identification. In this way lepton+track selected events increase by $\sim 30\%$ the total $t\bar{t}$ acceptance, in particular with respect to $W \rightarrow \tau\nu_\tau$ decays. The combined dilepton and lepton+track samples provide a cross section measurement of $\sigma_{t\bar{t}} = 6.2 \pm 0.9$(stat.) $\pm 0.7$(syst.) $\pm 0.5$ (lumi.) pb for $m_t = 175$ GeV/$c^2$, with a total relative uncertainty of 19% [2].

CDF reports three different measurements in the dilepton channel: $\sigma_{t\bar{t}} = 6.2 \pm 1.0$(stat.) $\pm 0.7$(syst.) $\pm 0.4$(lumi.) pb, using a data sample selected by requiring two well identified $e$ or $\mu$; $\sigma_{t\bar{t}} = 8.3 \pm 1.3$(stat.) $\pm 0.7$(syst.) $\pm 0.5$(lumi.) pb, and $\sigma_{t\bar{t}} = 10.1 \pm 1.8$(stat.) $\pm 1.1$(syst.) $\pm 0.6$(lumi.) pb, in the lepton+track and and lepton+track plus $b$-tag channels respectively [3].

In addition to the traditional analyses involving $e/\mu$ lepton pairs outline above, DØ reports measurements in the $e/\mu + \tau$ channel, which are of particular interest to look for effect beyond the SM, like those involving $t \rightarrow H^+b \rightarrow \tau\nu_\tau b$ decays. Events are selected requiring one well identified $e$ or $\mu$, and a $\tau$ candidate satisfying a Neural Network selection optimized for $\tau$-hadronic decays. In addition, at least one jets is required to be identified as originating from $b$-quark. The $t\bar{t}$ cross section is measured assuming SM branching ratios, including extra signal acceptance from $t\bar{t}$ events in the dilepton or lepton+jets channel in which one electron or a jets mimics the $\tau$-signature. The cross section is measured to be $\sigma_{t\bar{t}} = 8.3^{+2.0}_{-1.8}$(stat.) $^{+1.4}_{-1.2}$(syst.) $\pm 0.5$(lumi.) pb. On the other hand, assuming the SM cross section, the values of the exclusive $\sigma_{t\bar{t}} \times BR(t\bar{t} \rightarrow e + \tau + 2\nu + 2b)$ and $\sigma_{t\bar{t}} \times BR(t\bar{t} \rightarrow \mu + \tau + 2\nu + 2b)$ are found to be $0.19^{+0.12}_{-0.10}$(stat) $\pm 0.07$(syst.) pb, and $0.18^{+0.13}_{-0.11}$(stat) $\pm 0.09$(syst.) pb respectively [4]. These measurements are in good agreement with the SM expectation of 0.13 pb and 0.12 pb for the $e + \tau$ and $\mu + \tau$ channels respectively.

### 2.2  The Lepton+jets channel

Lepton+jets $t\bar{t}$ decays account for up to 43.5% of the total branching ratio when all lepton flavors are considered, and it is widely used for top-quark properties measurements.

In general, except for the results outlined in [5], the basic event selection requires one well-identified high-$p_T$ $e$ or $\mu$ ($p_T \geq 20$ GeV/$c$), missing transverse energy ($\not{E}_T \geq 20 \div 30$ GeV) and at least three high-$E_T$ jets ($E_T \geq 15 \div 20$ GeV), two of which can be required to satisfy $b$-tagging requirements. The dominant physics background originates from $W$+jets production, with small contributions from $Z \rightarrow \tau\tau$, single top and diboson production processes. Instrumental background is mainly due to fake isolated leptons in multijet events. Background contributions are calculated from Monte Carlo simulation and data.

To separate the $t\bar{t}$ signal from background contributions two approaches are followed. The first, in addition to the core selection outlined above, adopts $b$-jets identification algorithms to increase the sample purity. The second one, since no single kinematical variables provides sufficient discrimination power, makes use of a complex topological discriminant exploiting multiple kinematical properties of the events, $i.e.$ the $\Delta R$ between leptons and jets, or between jets, the total event transverse energy ($H_T$), aplanarity, and sphericity. The latter approach is of particular interest since it does not rely on $b$-tagging techniques, and is free from the $BR(t \rightarrow Wb) \sim 1$ assumption.

$D\emptyset$ reports results from a combination of these two techniques, using $0.9 fb^{-1}$, providing a $t\bar{t}$ cross section determination with a relative total uncertainty of $\sim 10\%$, at the same level of the theoretical uncertainty ($\sigma_{t\bar{t}} = 7.42 \pm 0.53$(stat.)$\pm 0.46$ (syst.) $\pm 0.45$(lumi.) pb [6]). Additionally a simultaneous measurement of the $t\bar{t}$ production cross section and of the ratio $R = \frac{BR(t \rightarrow Wb)}{BR(t \rightarrow Wq)}$ provides the best single measurement of the $\sigma_{t\bar{t}}$ to date: $8.18^{+0.90}_{-0.84}$ (stat.+syst.)$\pm 0.5$(lumi.) pb [7].

CDF reports different measurements of the $t\bar{t}$ cross section in the lepton+jets channel as well. The analysis requiring at least one identified $b$-jet in addition to the standard selection, measures $\sigma_{t\bar{t}} = 8.2 \pm 0.5$(stat.) $\pm 0.8$(syst.) $\pm 0.5$(lumi.) pb [8] ($\sim 13\%$ relative uncertainty). Other measurements using a topological discriminant or a combined secondary vertex and Neural Network tagger are reported in [9], for a data sample of approximately 0.7 fb$^{-1}$. The main sources of systematic uncertainty, as in the case of the dilepton channel, are due to lepton identification, jet energy scale, background and Monte Carlo normalization, and $b$-tagging efficiency.

### 2.3   The All-hadronic channel

The all-hadronic channel has the highest branching ratio (46.2%), but suffers from the largest background contribution. All-hadronic $t\bar{t}$ events are characterized by the basic signature of 6 or more high-$E_T$ jets, two of which originate from $b$-quark. The physics background is due to QCD multijet production, which can be reduced by applying specific topological and kinematical Neural Network based selection in combination with $b$-tagging requirements.

CDF and $D\emptyset$ report measurements[10] in this channel using 1.05 fb$^{-1}$ and 0.4 fb$^{-1}$ to be $\sigma_{t\bar{t}} = 8.3 \pm 1.0$(stat.) $^{+2.0}_{-1.5}$(syst.) $\pm 0.5$(lumi.) pb, and $\sigma_{t\bar{t}} = 4.5^{+2.0}_{-1.9}$(stat.) $^{+1.4}_{-1.1}$(syst.) $\pm 0.3$(lumi.) pb, respectively. The main systematics for these measurements is related to uncertainties in the jet energy scale.

## 3   Top quark production cross section properties, and probes toward new physics

### 3.1   Lepton+jets/dilepton cross section ratio

The ratio between $t\bar{t}$ cross section measurements in the lepton+jets and dilepton channel is sensitive to non-SM top decays: top quark pair decays involving a charged Higgs boson could enhance the observed lepton+jets cross section ratio, while lowering the dilepton one. $D\emptyset$ report a measurement of $R = \frac{\sigma_{t\bar{t}}^{l+jets}}{\sigma_{t\bar{t}}^{dil}} = 1.21^{+0.27}_{-0.26}$, in good agreement with the SM expectation of unity. Moreover, assuming a $m_{H^+} \sim m_W$, and $BR(H^\pm \rightarrow cs \sim 1)$, a 95% C.L. upper limit is set at 0.35 for the $BR(t \rightarrow H^+ b)$ [11].

### 3.2   Top pair production properties and resonance searches

Top quark pairs at the Tevatron center-of-mass energy ($\sqrt{s} = 1.96 TeV$) are produced mainly through quark-antiquark annihilation and gluon-gluon fusion processes. The relative fraction of gluon-gluon production processes, $F_{GG}$, is measured by CDF using 0.95 fb$^{-1}$. The result is obtained by combining two methods using low-$p_T$ track multiplicity and kinematical variables

to discriminate between the two production mechanisms. $F_{GG}$ is measured to be $0.07^{+0.15}_{-0.07}$ (stat+syst) and is constrained to be less than 0.38 at 95% C.L. [12], in good agreement with the SM expected value of 0.15.

The $t\bar{t}$ invariant mass spectra obtained in the lepton+jets channel is used by both collaborations to check for shape distortion effects or for the presence of bump yielded by physics processes beyond the SM. The technicolor $Z'$ has been excluded at 95% C.L. for masses below 760 GeV/$c^2$ (by DØ using 2.1 fb$^{-1}$) and 720 GeV/$c^2$ (by CDF using 0.95 fb$^{-1}$) [13].

Additionally, distortion of the $t\bar{t}$ invariant mass shapes due to the interference between quark-quark annihilation processes mediated by standard massless gluons and hypothetical massive ones has been checked by CDF using 1.9 fb$^{-1}$. The overall agreement with respect to the SM, in terms of massive gluon coupling strength, is within 1.7 $\sigma$ for massive gluon masses, $M_G$, from 400 to 800 GeV/c$^2$, and widths in the range $[0.05; 0.5]M_G$[14].

Finally, the differential cross section $d\sigma_{t\bar{t}}/dM_{t\bar{t}}$, corrected for detector resolution effects using regularized unfolding techniques, is measured using 1.9 fb$^{-1}$, and is found to be consistent with SM expectation with a probability of 45% [14].

## 4   Conclusions

The $t\bar{t}$ production cross section has been measured by CDF and DØ collaborations in different channels and using different methods. Possible hints of physics beyond the SM affecting $t\bar{t}$ production or decays are investigated using the cross section information, searching for shape distortions or bumps in the $t\bar{t}$ invariant mass spectra in the lepton+jets channel, or measuring cross section ratio in different channels. In all cases, current experimental measurements are in agreement with SM expectations. Many updates are foreseen for the Summer 2008.

## Acknowledgments

## References

1. M. Cacciari *et al.*, J. High Energy Phys. **0404** (2004) 068; N. Kidonakis *et al.*, Phys. Rev. D **68** (2003) 114014.
2. (DØ collaboration) DØ note 5477-CONF (2007).
3. (CDF collaboration) CDF note 8802, 8770, 8912 (2007).
4. (DØ collaboration) DØ note 5451-CONF (2007).
5. (CDF collaboration) Phys. Rev. Lett. **96** (2006) 202002; Phys. Lett. B **639** (2006) 172; (DØ collaboration) DØ note 5234-CONF (2006).
6. DØ collaboration) DØ note 5591-CONF (2008), submitted to PRL.
7. DØ collaboration) DØ note 5437-CONF (2007), submitted to PRL.
8. (CDF collaboration) CDF note 8795 (2007).
9. (CDF collaboration) CDF note 8092 (2006), 8272 (2007).
10. (DØ collaboration) Phys. Rev. D **76** (2007) 072007; (CDF collaboration) Phys. Rev. D **76**,(2007) 072009.
11. (DØ collaboration) DØ note 5466-CONF (2007).
12. (CDF collaboration) CDF note 9162 (2008).
13. (DØ/CDF collaboration) DØ note 5600-CONF (2008); CDF note 8675 (2007).
14. (CDF collaboration) CDF note 9164 (2008). CDF note 9157 (2008).